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Peak CO_2? China's Emissions Trajectories to 2050

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Abstract
As a result of soaring energy demand from a staggering pace of economic growth and the related growth of energy-intensive industry, China overtook the United States to become the world's largest contributor to CO_2 emissions in 2007. At the same time, China has taken serious actions to reduce its energy and carbon intensity by setting both short-term energy intensity reduction goal for 2006 to 2010 as well as long-term carbon intensity reduction goal for 2020. This study focuses on a China Energy Outlook through 2050 that assesses the role of energy efficiency policies in transitioning China to a lower emission trajectory and meeting its intensity reduction goals.

In the past years, LBNL has established and significantly enhanced the China End-Use Energy Model based on the diffusion of end-use technologies and other physical drivers of energy demand. This model presents an important new approach for helping understand China's complex and dynamic drivers of energy consumption and implications of energy efficiency policies through scenario analysis. A baseline ("Continued Improvement Scenario") and an alternative energy efficiency scenario ("Accelerated Improvement Scenario") have been developed to assess the impact of actions already taken by the Chinese government as well as planned and potential actions, and to evaluate the potential for China to control energy demand growth and mitigate emissions.

It is a common belief that China's CO_2 emissions will continue to grow throughout this century and will dominate global emissions. The findings from this research suggest that this will not likely be the case because of saturation effects in appliances, residential and commercial floor area, roadways, railways, fertilizer use, and urbanization will peak around 2030 with slowing population growth. The baseline and alternative scenarios also demonstrate that the 2020 goals can be met and underscore the significant role that policy-driven energy efficiency improvements will play in carbon mitigation along with a decarbonized power supply through greater renewable and non-fossil fuel generation.

Introduction
Rising CO_2 and other Greenhouse Gas (GHG) emissions largely resulting from fossil fuel combustion are contributing to higher global temperature and to significant climate change. Since China is still in the early stage of industrialization and modernization, the process of economic development will continue to drive China's energy demand and has already made China the world's largest CO_2 emitter in 2007. In recent years, China has taken serious actions to reduce its energy consumption and carbon emissions. China's 11th Five Year Plan (FYP) goal of reducing energy consumption per unit of GDP by 20% between 2006 and 2010 has been followed by extensive programs to support the realization of the goal. In Nov. 2009, China also committed to reduce its carbon intensity (CO_2 per unit of GDP) by 40% to 45% percent below 2005 levels by 2020. Achieving the 2020 goal will require strengthening and expansion of energy efficiency policies in industry, buildings, appliances, and motor vehicles, as well as further expansion of renewable and nuclear power capacity.

The past decade has seen the development of various scenarios describing long-term patterns of China's future GHG emissions. In most of these models, however, a description of sectoral activity variables is missing and end-use sector-level results for buildings, industry, or transportation or analysis of adoption of particular technologies and policies are generally not provided in global energy modeling efforts. This is a serious omission for energy analysts and policymakers, in some cases calling into question the very meaning of the scenarios. Energy consumption is driven by the diffusion of various types of equipment;

the performance, saturation, and utilization of the equipment has a profound effect on energy demand. Policy analysts wishing to assess the impacts of efficiency, industry structure and mitigation policies require more detailed description of drivers and end use breakdown.

This study focuses on a China Energy Outlook through 2050 with 2020 and 2030 milestones that assesses the cross-sectoral roles of energy efficiency policies and structural change in industry for transitioning China's economy to a lower emissions trajectory and examines the likelihood of meeting China's 2020 goal. This outlook is based on the LBNL China End-Use Energy Model, which addresses end-use energy demand characteristics including sectoral patterns of energy consumption, change in subsectoral industrial output, trends in saturation and usage of energy-using equipment, technological change including efficiency improvements, and links between economic growth and energy demand. Two scenarios are developed to evaluate the impact of different levels of energy efficiency and power sector policies on controlling energy demand growth and emission mitigation and progress towards meeting its 2020 goal.

Modeling Methodology

The LBNL China End-Use Energy Model has been significantly enhanced since its establishment in 2005 and is based on level of diffusion of end use technologies and other drivers of energy demand on a sectoral level and includes both demand and supply-side modules. Built using the LEAP (Long-Range Energy Alternatives Planning) modeling software developed by Stockholm Environmental Institute, this model enables detailed consideration of technological development—industrial production, equipment efficiency, residential appliance usage, vehicle ownership, power sector efficiency, lighting and heating usage—as a way to evaluate China's energy and emission development path below the level of its macro-relationship to economic development. Within the energy consumption sector, key drivers of energy use include activity drivers (total population growth, urbanization, building and vehicle stock, commodity production), economic drivers (total GDP, income), energy intensity trends (energy intensity of energy-using equipment and appliances). These factors are in turn driven by changes in consumer preferences, energy costs, settlement and infrastructure patterns, technical change, and overall economic conditions. From the supply-side, the energy transformation sector includes a power sector module which can be adapted to reflect changes in generation dispatch algorithms, efficiency levels, fuel-switching, generation mix, installation of carbon capture and sequestration technology and demand side management.

This study uses two scenarios, Continued Improvement and Accelerated Improvement, to represent distinct alternatives in long-term pathways given current trends, macroeconomic considerations, currently available and projected efficiency technologies, and policy choices and degree of successful implementation of the policies.

Continued Improvement Scenario (CIS)

The 'Continued Improvement Scenario' does not assume that current technologies will remain 'frozen' in place, but that the Chinese economy will continue on a path of lowering its energy intensity. Efficiency improvements in this scenario are consistent with trends in 'market-based' improvement and successful implementation of policies and programs already undertaken, planned or proposed by the Chinese government. Since CIS reflects what is expected to happen in terms of policy implementation and efficiency improvement, it is used as the reference scenario for evaluating energy savings and emission reduction potential.

Accelerated Improvement Scenario (AIS)

The 'Accelerated Improvement Scenario' assumes a much more aggressive trajectory toward current best practice and implementation of important alternative energy technologies as a result of more aggressive and far-reaching energy efficiency policies. Efficiency targets are considered at the level of end-use technologies, with Chinese sub-sector intensities being lowered by implementation of the best technically feasible products and processes in the short to medium term, taking into account the time necessary for these technologies to penetrate the stock of energy-consuming equipment. The key energy efficiency policies driving different paces of efficiency improvements in the two scenarios are highlighted in Table 1 below.

Table 1 Key Assumptions of Two Scenarios

	Policy Drivers	Continued Improvement	Accelerated Improvement
Macroeconomic Parameters			
Population in 2050	-	1.41 Billion	1.41 Billion
Urbanization Rate in 2050	-	79 %	79%
GDP Growth	-		
2010-2020	-	7.7%	7.7%
2020-2030	-	5.9%	5.9%
2030-2050	-	3.4%	3.4%
Residential Buildings			
Appliance Efficiency	Efficiency standards revision, strengthened enforcement of Energy Label	Moderate Efficiency Improvement (1/3 improvement relative to High Efficiency)	Moderate Improvement of new equipment in 2010 – near Best Practice by 2020
Building Shell Improvements: Heating		Moderate Efficiency Improvement (1/3 improvement relative to High Efficiency)	50% improvement in new buildings by 2010 – 75% improvement in new buildings by 2020.
Building Shell Improvements: Cooling		Moderate Efficiency Improvement (1/3 improvement relative to High Efficiency)	25% improvement in new buildings by 2010 – 37.5% improvement in new buildings by 2020.
Commercial Buildings			
Heating Efficiency	Strengthening equipment efficiency standards, incentives for heat pump installation	Moderate Efficiency Improvement by 2020	Current International Best Practice by 2020
Cooling Efficiency	Strengthening equipment efficiency standards	Current International Best Practice by 2050	Current International Best Practice by 2020
Building Shell Improvements: Heating		50% improvement in fraction of new buildings growing by 1% per year	50% improvement in all new buildings by 2010, 75% improvement in all new buildings by 2025
Building Shell Improvements: Cooling		25% improvement in fraction of new buildings growing by 1% per year	25% improvement in all new buildings by 2010, 37.5% improvement in all new buildings by 2025
Lighting and Equipment Efficiency	New commercial equipment efficiency standards, phase-out of inefficient lighting	18 % improvement relative to frozen efficiency by 2030	48 % improvement relative to frozen efficiency by 2030
Industrial Sector			
Cement	Continuation of Top 1000 Program, setting and enforcement of sector-specific energy intensity target such as the 11th FYP targets.	Current world best practice for Portland cement by ~2025	Current world best practice for Portland cement by ~2020
Iron & Steel		25% of production by electric arc furnace by 2050	40% of production by electric arc furnace by 2050
Aluminum		Moderate decline of energy intensity to 2050	Accelerated decline of energy intensity to world best practice levels before 2050
Paper		Moderate weighted average energy intensity reduction	Current world best practice energy intensity by 2030
Ammonia		Moderate energy intensity reductions without achieving all 11th FYP target	Achieve all 11th FYP targets through 2020 with continued decline thereafter
Ethylene		Meets 11th FYP energy intensity targets through 2020 and continuing reduction	Current world best practice by 2025 and continuing reduction through 2050
Glass		Moderate efficiency improvements	National average efficiency reach Shandong Top 1000 Program's best practice level by 2030
Transport Sector			
ICE Efficiency Improvements	Strengthening existing fuel economy standards for cars and trucks, incentives or rebates for efficient car purchases, gasoline tax	Moderate efficiency improvements in fuel economy of aircrafts, buses, cars, and trucks through 2050	Significant additional efficiency improvements in fuel economy of buses through 2050

Electric Vehicle (EV) Penetration	EV mandates or targets for government fleet, economic incentives for private EV purchase	Electric vehicle penetration to 30% by 2050	Electric vehicle penetration to 70% by 2050
Rail Electrification	Public investment in upgrading and expanding rail network	Continued rail electrification to 70% by 2050	Accelerated rail electrification to 85% by 2050
Power Sector			
Thermal Efficiency Improvements	Mandate closure of small inefficient coal generation units, require	Coal heat rate drops from 357 to 290 grams coal equivalent per kilowatt-hour (gce/kWh) in 2050	Coal heat rate drops from 357 to 275 (gce/kWh) in 2050
Renewable Generation Growth	Renewable Portfolio Standard or Mandatory Market Share for renewables, feed-in tariff. Environmental dispatch order	Installed capacity of wind, solar, and biomass power grows from 2.3 GW in 2005 to 535 GW in 2050	Installed capacity of wind, solar, and biomass power grows from 2.3 GW in 2005 to 608 GW in 2050
Demand Side Management	Various demand-side efficiency programs and policies	Total electricity demand reaches 9100 TWh in 2050	Total electricity demand reaches 7,764 TWh in 2050

Aggregate Energy and Emissions Modeling Results

Contextualizing China's Energy and Emissions Outlook

By 2050, China's primary energy consumption will rise continuously in both scenarios but approach a plateau starting in 2025 for AIS and 2030 for CIS (Figure 1). Energy demand grows from 2250 million tonnes of coal equivalent (Mtce[1]) to 5500 Mtce (161 EJ) in 2050 under CIS. It is reduced by 900 Mtce to 4600 Mtce in AIS in 2050, a cumulative energy reduction of 26 billion tonnes of coal equivalent from 2005 to 2050. If sufficient CCS capacity to capture and sequester 500 Mt CO_2 by 2050 was implemented under the CIS scenario, total primary energy use would increase to 5520 Mtce in 2050 due to CCS energy requirements for carbon separation, pumping and long-term storage, but carbon emissions would decline by 4% in 2050.

The notable difference between LBNL's scenarios and others is the shape of the energy and emissions trajectories. LBNL's projected energy consumption increases at approximately the same rate as other models, but diverge after 2030 with a slow down or plateau whereas others still exhibit extrapolation of growth all the way out to 2050. This also results in the lower projected primary energy consumption in 2050 under LBNL's scenarios. Most of the alternative scenarios examined have relied on the CCS application to bring down emissions. However, the LBNL CIS with CCS scenario demonstrates that all else equal, there would be a net increase in primary energy demand on the order of 36 Mtce more by 2050 due to CCS energy requirements for pumping, separation and sequestration.

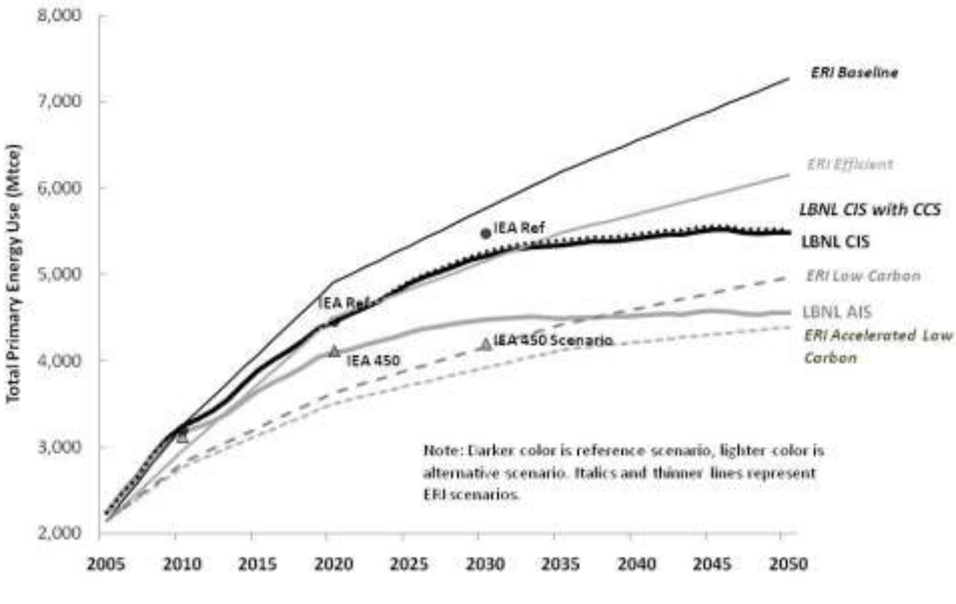


Figure 1. Primary Energy Consumption in Different Scenarios

[1] Mtce is the standard energy unit used in China. 1 Mtce is approximately equivalent to 29.3 PJ.

Note: AIS is Accelerated Improvement Scenario, CIS is Continued Improvement Scenario, ERI is China Energy Research Institute, whose recent 2009 study results have been converted to IEA-equivalent figures given that ERI follows the convention of using power generation equivalent, rather than IEA and LBNL's use of calorific equivalent, to convert primary electricity (ERI, 2009). This conversion of ERI results to the IEA/LBNL convention reduces the gross energy content of electricity generated from renewables and biomass by 66%.. IEA results are taken from World Energy Outlook 2009.

As seen in Figure 2, CO_2 emissions under both scenarios approach a plateau or peak in 2025 (AIS) and 2030 (CIS). CIS reaches a plateau between 2030 and 2035 with 12 billion tonnes in 2033, while the more aggressive energy efficiency improvement and faster decarbonisation of the power supply under AIS result in a peak between 2025 and 2030 at 9.7 billion tonnes in 2027. CCS at the current level of efficiency and from integrated system point of view, however, will only have a small net CO_2 mitigation impact of 476 million tonnes in 2050 assuming 500 million tonnes of capacity in place. There is greater range in CO_2 emissions outlook amongst different studies, and CIS and AIS are both notable in being two of the only three scenarios that see emissions peaks before 2050. In fact, emissions peak is the earliest in CIS and AIS and underscore the important role that energy efficiency policies can play in carbon mitigation in the absence of carbon capture and sequestration.

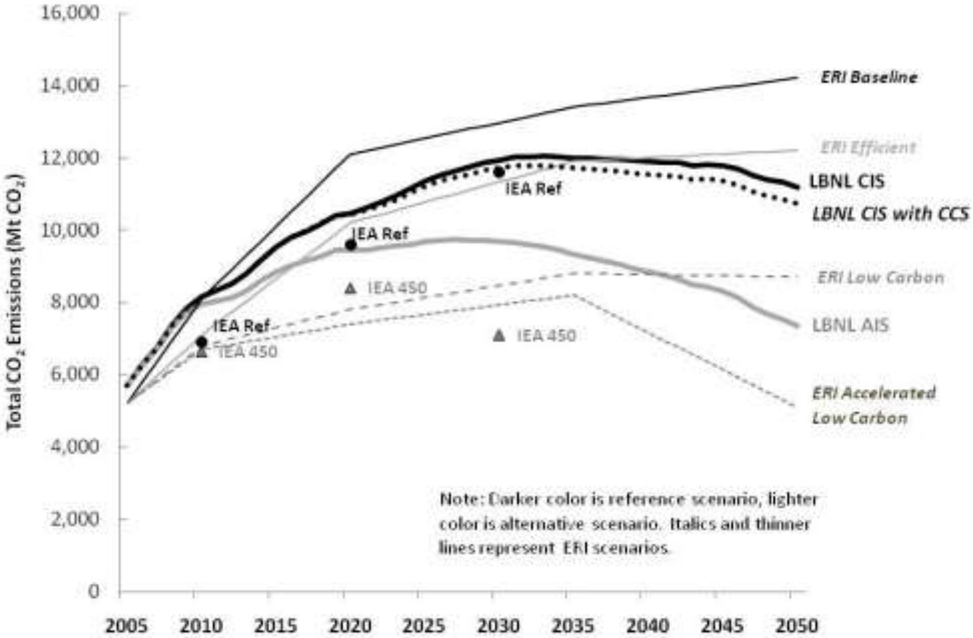


Figure 2. CO_2 Emissions in Different Scenarios

Aggregate Results by Fuel and Sector

The share of coal will be reduced from 74% in 2005 to about 47% by 2050 in CIS, and could be further reduced to 30% in AIS (

Figure 3). Instead, more energy demand will be met by primary electricity generated by renewable, hydro and nuclear, which could reach 32% by 2050 with further decarbonisation in power sector under the AIS. Petroleum energy use will grow both in absolute term and the relative share to overall energy consumption, attributing to increase in vehicle ownership as well as freight turnover in transportation sector.

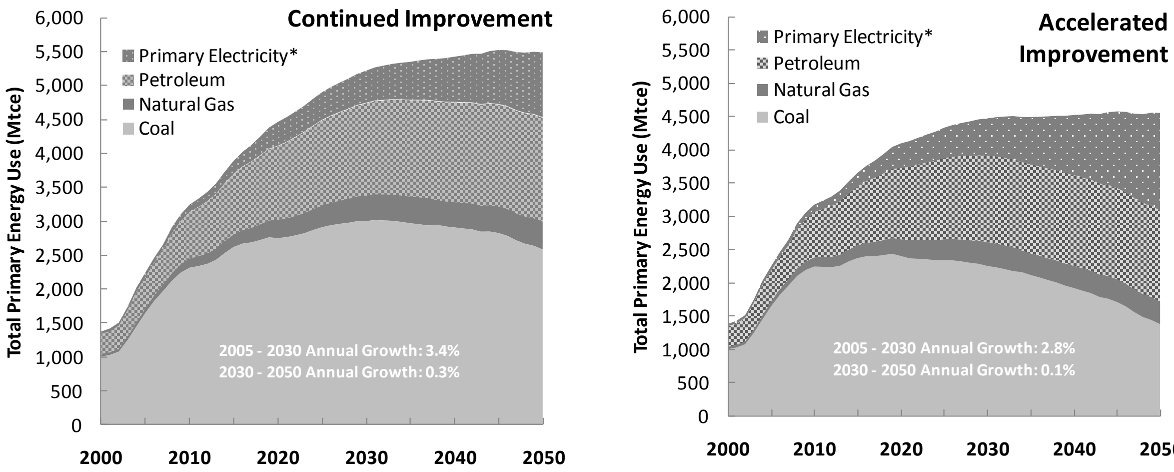


Figure 3. Total Primary Energy by Fuel Type, CIS and AIS

**Note: Primary Electricity includes hydropower, wind, solar and other renewable at calorific equivalent for conversion.*

Sectorwise, the single largest emission reduction potential could be seen in building sector, particularly residential buildings, followed by the industrial sector, as illustrated in Figure 4. The industrial sector shows early achievement in emission reduction, but in long-run, more reduction could be achieved through more aggressive policies, measures and technology improvement in building sector and lead to more than half of the emission reduction over the 45 year period. Under CIS, the commercial sector will be responsible for nearly one-third of all electricity demand. Under AIS, the transport sector has growing share of electricity demand because of more aggressive rail and road electrification.

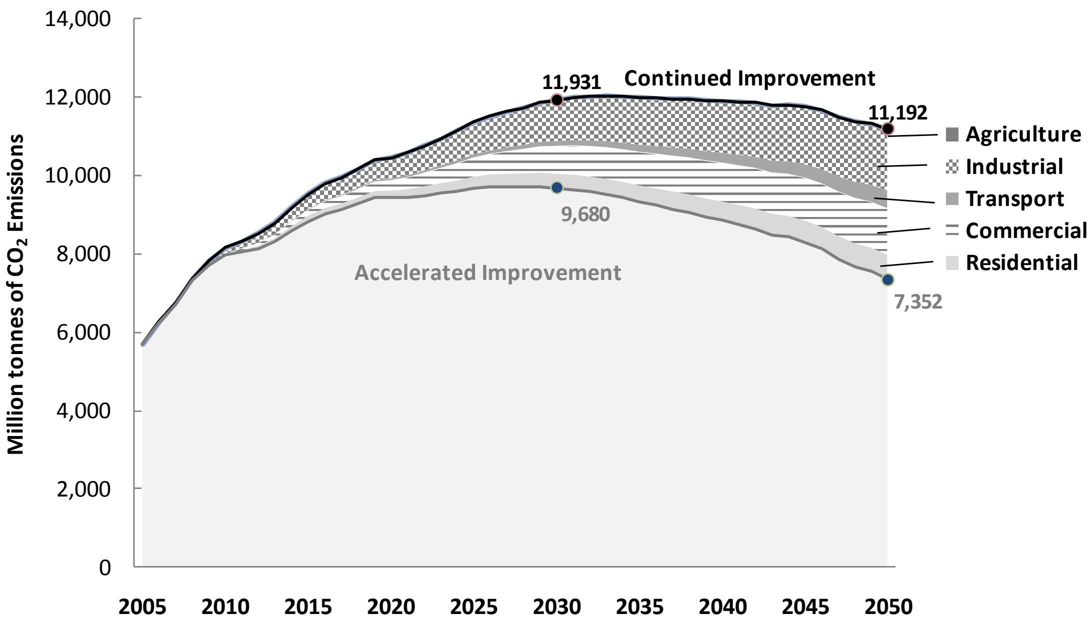
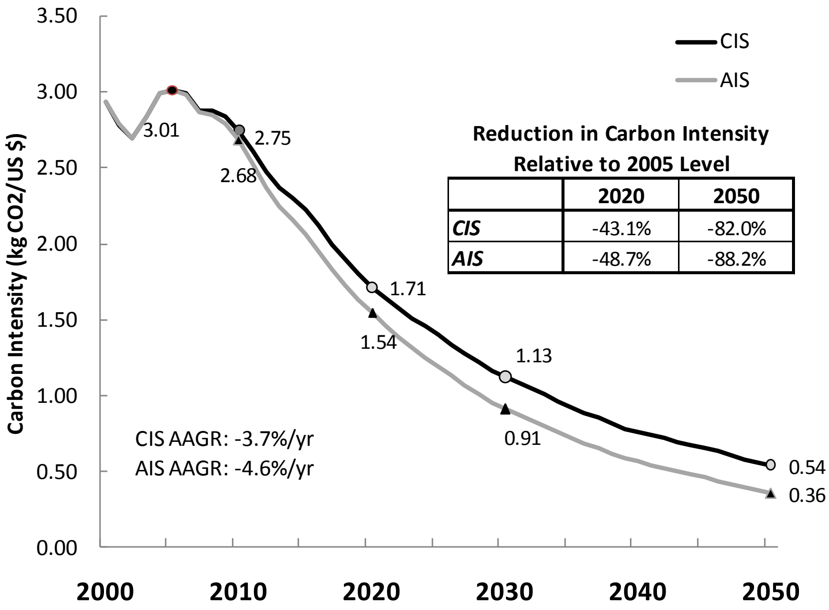


Figure 4. CO_2 Emissions Difference between Two Scenarios by Sector

Overall, the growth of annual energy demand in China could range from 3.4% (CIS) to 2.8% (AIS) between 2005 and 2030 and 0.3% to 0.1% between 2030 and 2050. In contrast, carbon intensity declines over this period, with annual average reductions of 3.7% for CIS and 4.6% for AIS from 2005 to 2050 (Figure 5). More importantly, China will meet and even surpass its 2020 carbon intensity reduction goal of 40% to 45% under CIS and AIS, respectively. It will, however, require strengthening or expansion of energy efficiency policies in industry, buildings, appliances, and motor vehicles, as well as further expansion of renewable and nuclear power capacity. With aggressive implementation of energy efficiency policies and decarbonization of the power sector under AIS, China could reduce its 2005 carbon intensity by as much as 88% by 2050.



Reduction in Carbon Intensity Relative to 2005 Level

	2020	2050
CIS	-43.1%	-82.0%
AIS	-48.7%	-88.2%

Figure 5. Carbon Intensity Reductions by Scenario

Residential Sector Findings

Although the ownership of many appliances has saturated in urban areas, new sales remain strong over the period because of the rise in urbanization, with over 470 million additional people expected to become urban residents by 2050. As a result, electricity use from appliances will grow rapidly. Urban fuel consumption from space heating will more than double, due to increases in urban population and heating intensity in both CIS and AIS. Rural electricity consumption will continue to grow in spite of the reduction in rural population due to increases in per household use of lighting and appliances. Biomass consumption will decrease considerably, with substitution of commercial fuels.

Residential primary energy demand will grow rapidly until 2025 or 2030. In CIS, demand rises between 2005 and 2030 at an average annual rate of 2.8%. After 2030, it increases by only 0.6% per year. This slowing of growth is largely due to saturation effects, as the process of urbanization will be largely complete, most households will possess all major appliances by 2030, and efficiency improvements in heat distribution will be largely complete. Figure 6 shows the energy savings opportunity in the residential sectors distributed across end-uses, with appliances and space heating having the largest savings potential from efficiency policies. From 2005 to 2050, accelerated adoption and implementation of more aggressive efficiency policies such as strengthened appliance standards and expansion of the China Energy Label could lead to total CO_2 emissions reduction of 18.4 billion tonnes under AIS.

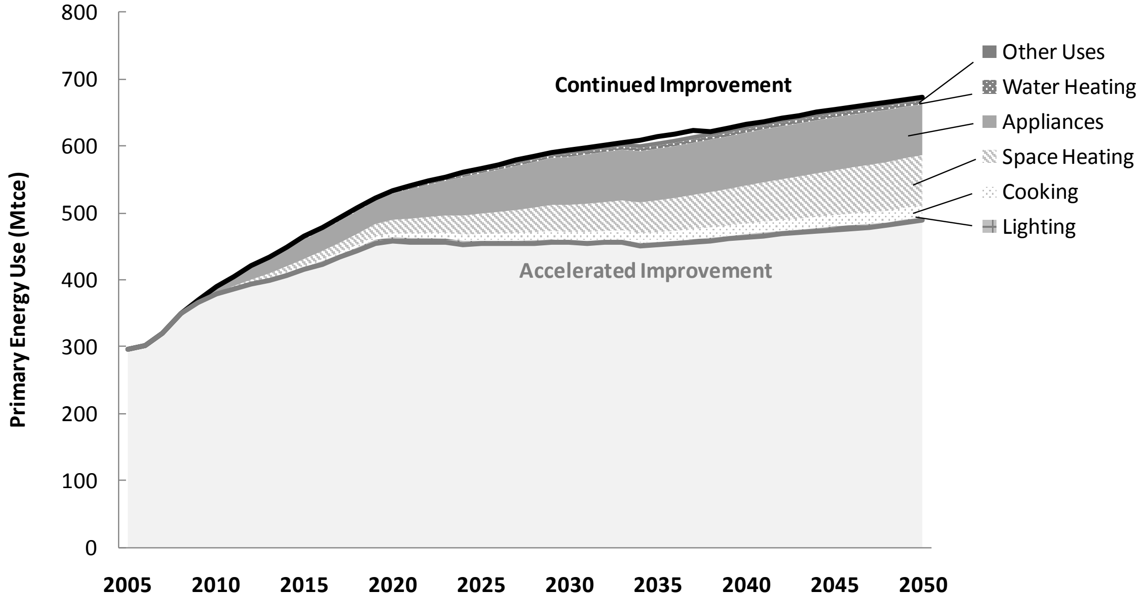


Figure 6. Residential Primary Energy Use and Potential Reductions by End-Use

Commercial Sector Findings

Energy demand in the commercial sector is currently growing rapidly, but there will be a slowing of growth in the medium term, reaching a plateau by about 2030. Total commercial building floorspace may saturate in the short term, but end-use intensity continues to have much room to grow before reaching current levels in industrialized countries. In particular, the lighting, office equipment and other plug loads in commercial buildings will grow dramatically through 2030, but then level off thereafter in CIS.

The main dynamic of energy consumption in commercial buildings revealed by this study is that energy growth will be largely dominated by intensity increases, rather than overall increases in commercial floor area. Increases in commercial building space will be limited by the number of workers available to this sector in China's future, while the economic activity in this sector will continue to gain in significance, growth in the physical infrastructure will by no means keep up with growth in value added GDP. With rising commercial end-use energy intensity expected, building efficiency policies will be important in controlling energy demand growth and CO_2 mitigation. Annual carbon mitigation under AIS could reach 1180 million tonnes of CO_2 by 2030, or cumulative reduction of nearly 26 billion tonnes of CO_2 emissions (Figure 7).

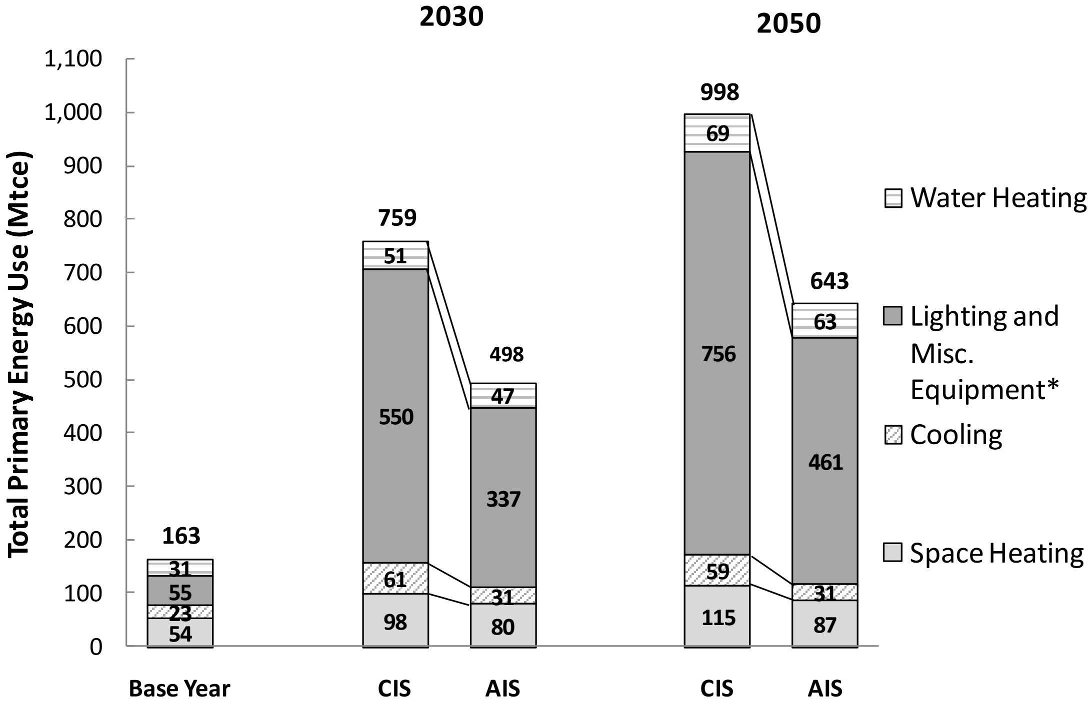


Figure 7. Commercial Primary Energy by End-Use

**Lighting and misc. equipment refers to equipment such as computers, printers, audiovisual equipment, elevators, pumps, etc.*

Industrial Sector Findings

Within industry, the energy consumption of the seven sectors singled out in China's long-term development plan for substantial energy efficiency improvements will gradually decline relative to other sectors, though still account for 47% of total energy consumption in 2050, down from 61% in 2005 in CIS scenario. In the case of iron and steel and cement in particular, China's expected transition from rapid industrialization and infrastructure development to more intensive growth and expansion in the services sector after 2010 underlies the slowdown and eventual decline in total iron and steel output and in the growth of the cement industry. Among "Other Industry", steady increases in energy consumption growth are expected from the refining sector, the coal mining and extraction sector, and the oil and gas exploration and production sector as well as from manufacturing.

Energy demand in China is currently dominated by a few energy-intensive sectors, particular by the main construction inputs – cement and iron and steel. The recent explosion of construction in China has had a driving role in these industries, and therefore Chinese energy demand as a whole. The slowing of this construction boom will therefore have a major impact as seen by the peaking of industrial primary energy use around 2030.

The energy use of each of these sub-sectors in absolute terms all decline modestly over time. The only exception is in energy use by the ethylene sub-sector, which grows notably from a 4% share of total industrial energy use in 2005 to 11% share in 2030 (Figure 8). The model results for projected CIS and AIS industrial energy use reflect key differences in only efficiency improvements, with a 290 Mtce reduction in energy use under the AIS scenario in 2030, and 274 Mtce in 2050. This translates into annual CO_2 emission reduction of 1550 million tonnes in 2050, or 40% of all emission reductions, and cumulative reduction of nearly 39 billion tonnes by 2050.

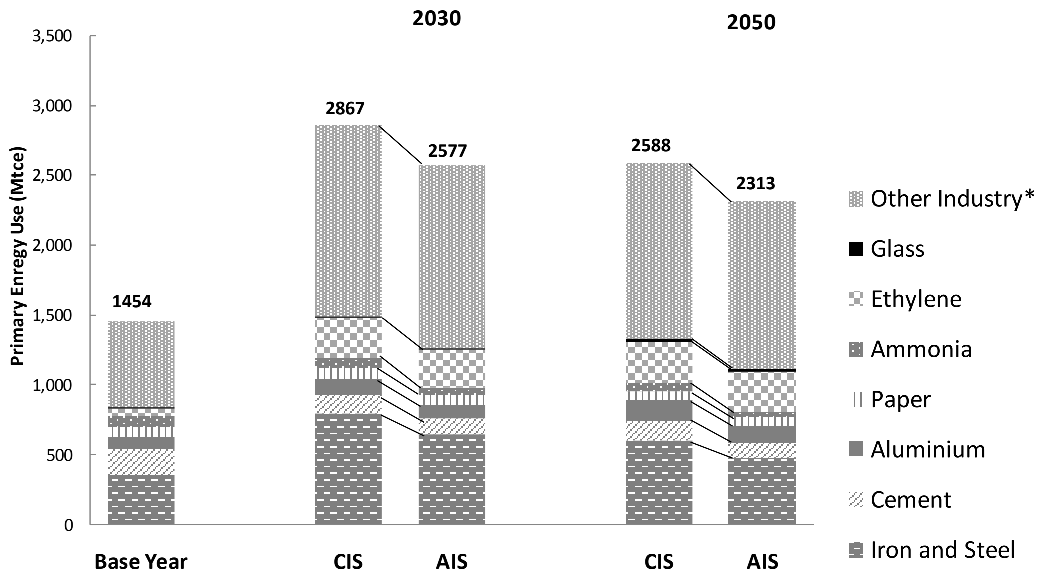


Figure 8. Industrial Primary Energy Use by Subsector

**Other Industry includes manufacturing, chemicals, light industry and all other small industrial subsectors.*

The more efficient AIS development trajectory has differing impacts on energy reduction in each of the seven industrial sub-sectors (Figure 9). Between 2005 and 2050, the iron and steel, other industry and cement sub-sectors comprise the largest energy reduction potential under both CIS and AIS scenario when compared to other sub-sectors. The ethylene sub-sector stands out as an exception with negligible energy savings under AIS, partly because energy consumption actually grows from 2010 through 2030 under both scenarios.

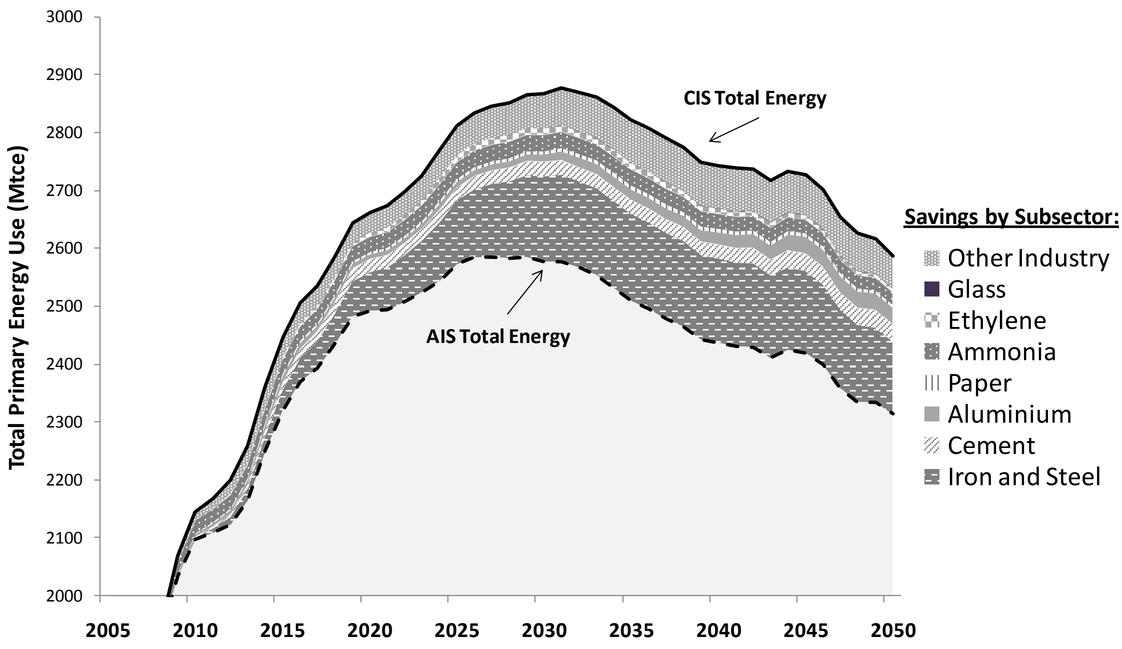


Figure 9. Industrial Energy Savings Potential by Subsector

Note: Y-scale not set to zero.

Transport Sector Findings

The greatest growth for energy demand in the transport sector will be from passenger road transportation, with urban private car ownership expected to increase to over 356 million vehicles by

2050. In primary energy terms, the impact of improved efficiency in motor vehicles and accelerated electrification of passenger cars and the national rail system lowers total transportation energy use in 2050 by 107 Mtce compared to the CIS (Figure 10). Increasing the 2050 proportion of electric cars from 30% in CIS to 70% in AIS reduces annual gasoline demand by 100 million tonnes of oil equivalent, but increase annual electricity demand by 265 TWh in 2050. This produces the unintended result that China becomes a gasoline exporter, as demand for other oil products is not reduced commensurately.

Energy use for freight transport remains important in both scenarios and has a strong impact on the structure of petroleum demand. Although foreign trade becomes less important to 2050 as China relies more on domestic demand, bunker fuel (heavy oil) demand will continue to rise strongly. Increased fuel efficiency of trucks for road freight, higher levels of electrification of the rail system, and more efficient inland and coastal ships moderate diesel demand growth, but diesel remains the largest share of petroleum product demand.

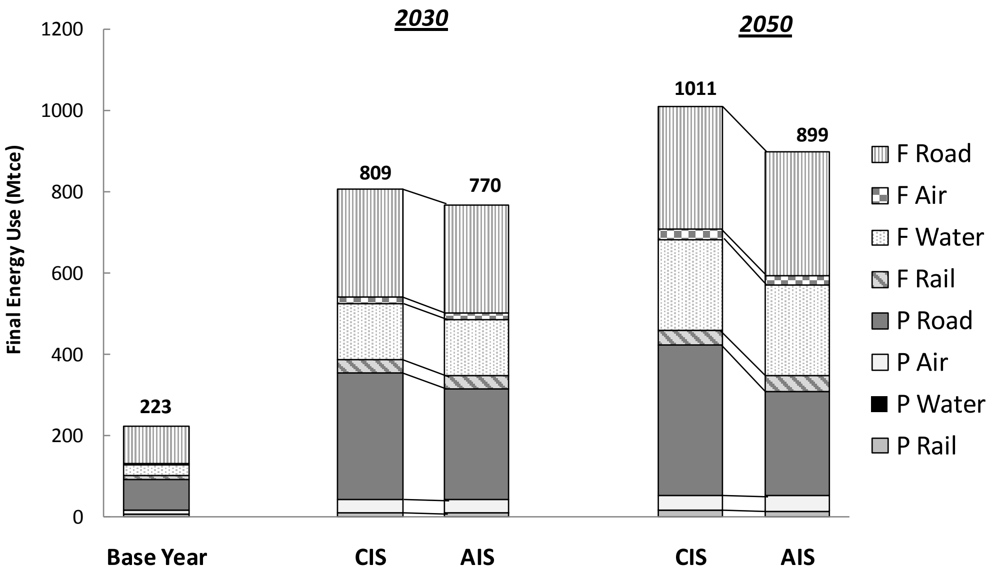


Figure 10. Transport Final Energy Consumption by Mode

Power decarbonization has important effects on the carbon mitigation potential of switching to electric cars technology. Greater transport electricity use under AIS could result in net CO_2 reduction on the order of 5 to 10 Mt CO_2 per year before 2030 and as much as 109 Mt CO_2 by 2050 because AIS power supply is less carbon intensive than CIS power supply (Figure 11). However, in the absence of any decarbonization in the power sector, EVs will increase CO_2 emissions.

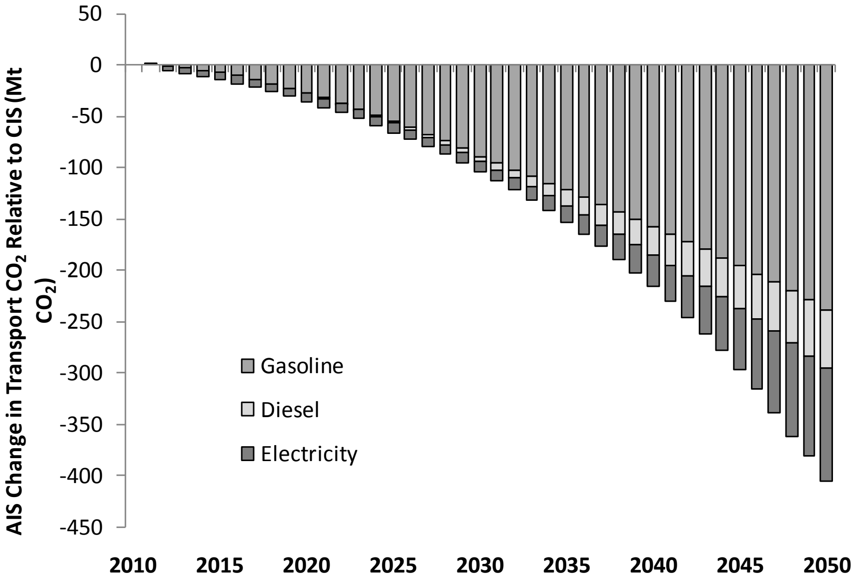


Figure 11. Transport CO_2 Emission Reduction under AIS by Fuel Source

Power Sector Findings

The electricity sector accounts for a large growing share of China's energy use and related carbon emissions. On the demand side, AIS results in 15% lower total electricity generation in 2050 than CIS. On the supply side, efficiency improvements and fuel substitutions bring the 2050 coal share of total electricity generation from 49% in the continued improvement scenario to 10% in the accelerated improvement scenario.

Table 2. Power Generation Shares by Technology, CIS and AIS

		CIS		AIS	
	2005	**2030**	**2050**	**2030**	**2050**
Wind Power	0%	6%	13%	10%	16%
Nuclear Power	2%	13%	25%	19%	54%
NG Fired CC	1%	2%	2%	4%	2%
Hydropower	15%	12%	12%	17%	16%
Oil Fired Units	2%	0%	0%	0%	0%
Biomass and other Renew	0%	1%	1%	1%	1%
Solar	0%	1%	1%	1%	1%
Coal <100MW	21%	0%	0%	0%	0%
Coal 100-200 MW	11%	0%	0%	0%	0%
Coal 200-300 MW Subcritical Units	9%	0%	0%	0%	0%
Coal 300-600 MW Subcritical Units	35%	1%	0%	0%	0%
Coal 600-1000 MW Supercritical Units	2%	22%	8%	19%	0%
Coal >1000MW Ultra Supercritical Units	0%	44%	41%	30%	9%
Total Electricity Generation (TWh)	*2620*	*7830*	*9100*	*6560*	*7760*

Decarbonization also plays a significant role in carbon emission reduction in the power sector and substantially outweighs the potential impact of carbon capture and sequestration (CCS). Besides the CIS and AIS scenarios of power sector development, an addition scenario was added to represent the implementation of CCS to capture 500 Mt CO_2 by 2050 under the CIS pathway of efficiency improvement and fuel shifting. Of the three scenarios, the AIS scenario requires the least primary energy and produces significantly lower energy-related power sector carbon dioxide emissions than either CIS or the CCS scenario. In fact, AIS power sector emissions peak just below 3 billion tonnes in

2019 and begin declining rapidly thereafter to 0.6 billion tonnes in 2050. The CCS base scenario results in 476 million tonnes less emissions in 2050 than the CIS scenario with a 1.4% increase in the total primary energy requirement for carbon capture, pumping and sequestration.

Within the power sector, the greatest carbon emissions mitigation potential under AIS is from direct electricity demand reduction as a result of more aggressive policy-driven end-use efficiency improvements in industrial, residential, commercial, and transport sectors. **Figure 12** illustrates five wedges that lead to power sector emissions reductions of almost 3.5 billion tonnes of CO_2 per year by 2030, where the solid wedges represent CO_2 savings from various power sector changes and the stripped wedge represents CO_2 savings from electricity demand reduction. One of the largest power sector mitigation potential is from end-use efficiency improvements that lower final electricity demand and the related CO_2 emissions, which is about half of total CO_2 savings before 2030 and then one-third of total CO_2 savings by 2050. Another growing source of carbon mitigation potential is the rapid expansion of nuclear generation, which increases from accounting for only 5% of CO_2 savings in 2030 to almost 40% in 2050. Of the CO_2 savings from power sector technology and fuel switching, greater shifts in coal generation technology (i.e., greater use of supercritical coal generation) and higher renewable and hydropower capacity each contribute similar magnitude of savings by 2050. These results emphasize the significant role that energy efficiency improvements will continue to play in carbon mitigation in the power sector (vis-à-vis lowering electricity demand), as efficiency improvements and can actually outweigh CO_2 savings from decarbonized power supply through greater renewable and non-fossil fuel generation prior to 2030.

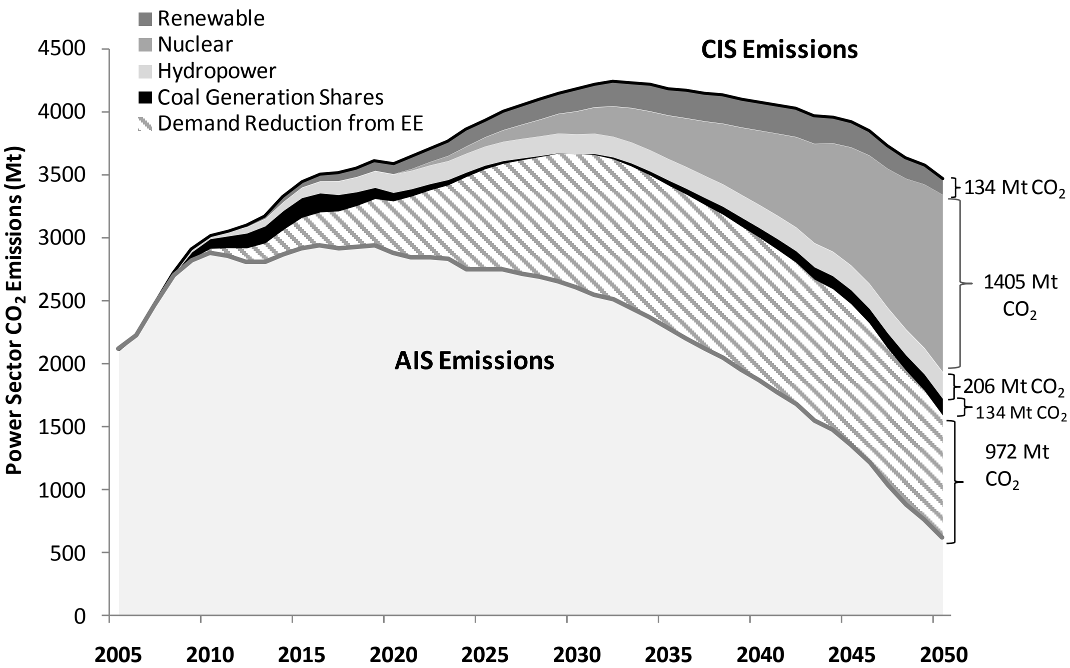


Figure 12. AIS Power Sector CO_2 Emissions Reduction by Source

Sensitivity Analysis

Sensitivity analysis of drivers in the key economic sectors was completed to evaluate uncertainties that exist in the model. In each sensitivity analysis scenario, a specific variable such as the urbanization level was tested for its impact on total primary energy use under the Continued Improvement scenario, ceteris paribus. The results of the sensitivity parameters tested that had the highest level of uncertainties with changes of at least 300 Mtce (or 5% of total primary energy use) in 2050 are presented in **Figure 13**. Amongst the different sensitivity analysis scenarios tested, variables in the industrial sector had the largest impact on total primary energy use, implying that there is a higher level of uncertainty surrounding these variables. For example, a 25% increase in the growth rate of other industry GDP which directly affects steel production for use in manufacturing can result in an increase of nearly 800 Mtce in total primary energy use by 2050. Likewise, uncertainties in the levels of heavy industrial output and in the energy intensity of "other industry" can result in changes in total primary energy use in the range of 300 to 700 Mtce in 2050.

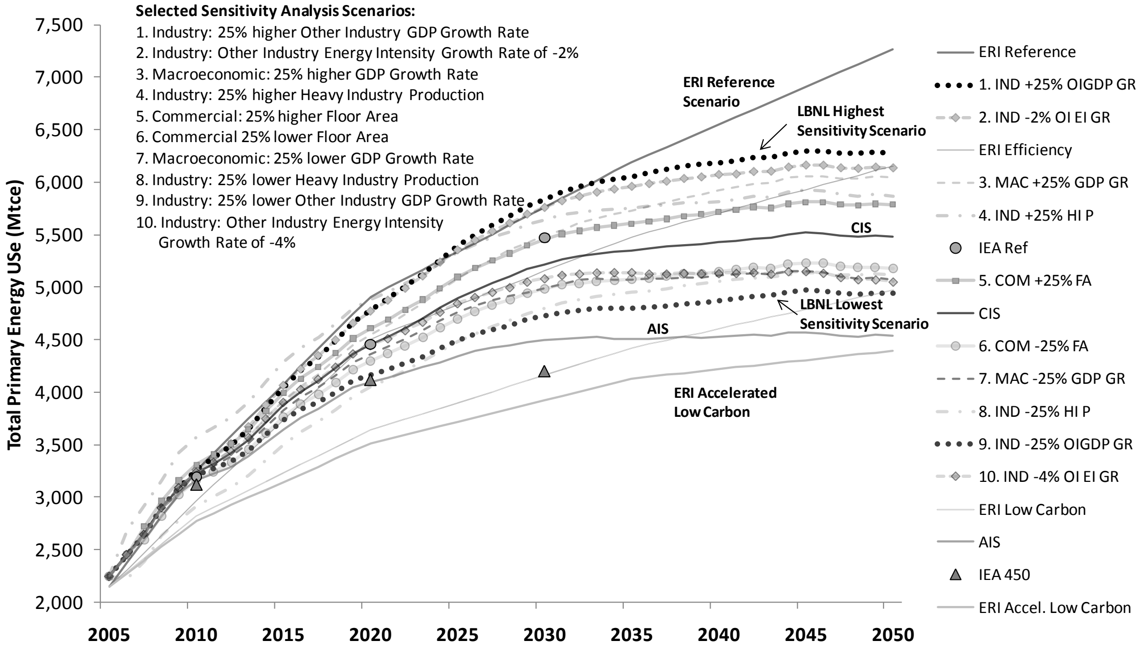


Figure 13. Sensitivity Analysis Scenario Results with Greatest Uncertainty

The other variables included in the sensitivity analysis that resulted in medium (impact of greater than 50 Mtce or 1%) or low (impact of less than 50 Mtce) uncertainties are outlined in the table below.

Sensitivity Scenario Name	Sensitivity Scenario Description	Sensitivity Impact
MAC 67% Urban	Macroeconomic: 67% urbanization by 2050	Medium
RES +25% FA	Residential: 25% more floor area per capita	Medium
COM 25 Life	Commercial: 25 years building lifetime	Medium
COM 50 Life	Commercial: 50 years building lifetime	Medium
COM +25% LOI	Commercial: 25% higher lighting & other end-use intensity	Medium
COM -25% LOI	Commercial: 25% lower lighting & other end-use intensity	Medium
TRA 40% EV AIS*	Transport relative to AIS*: 40% Electric Vehicle share of cars by 2050	Low
TRA 20% EV CIS	Transport: 20% Electric Vehicle Share of cars by 2050	Low
TRA -25% OFA	Transport: 25% lower Ocean Freight Activity	Low
IND 60% EAF	Industry: 60% EAF furnace penetration in steel production by 2050	Medium
IND 25% EAF	Industry: 25% EAF furnace penetration in steel production by 2050	Low

Conclusions

As China continues to pursue its social development goals, demand for energy services are set to grow, presenting fundamental challenges as economic growth and projected rapid urbanization will drive up energy demand and CO_2 emissions without changes in energy efficiency and energy supply structure. This study thus evaluated how China can maintain its development trajectory, provide basic wealth to it citizens while being energy sustaining; assessed the role of energy-efficiency as well as structure change in potential GHG emissions abatement policies for transitioning China's economy to a lower-GHG trajectory; and evaluated China's long-term domestic energy supply in order to gauge the potential challenge China may face in meeting long-term demand.

By 2050, primary energy consumption will rise continuously in both scenarios but reach a plateau around 2040, with a cumulative energy reduction of 26 billion tonnes of coal equivalent under the Accelerated Improvement Scenario from 2005 to 2050. Future energy demand reduction potential is greatest in the industry sector in the earlier years and from the buildings sector in the long run.

CO_2 emissions under both scenarios could experience a plateau or peak around 2030, with AIS peaking slightly earlier at 9.7 billion tonnes of CO_2 as a result of more aggressive energy efficiency improvement and faster decarbonisation of the power supply. The single largest end-use sector emission reduction potential could be seen in the buildings sector, particularly commercial buildings, followed by industry sector. Further reduction of CO_2 under these scenario assumptions would require even higher levels of non-carbon-emitting electricity. The total national emissions mitigation potential of moving from a CIS to AIS trajectory of development is 3.8 billion tonnes in 2050 with the power sector having the greatest mitigation potential.

Both the CIS and AIS scenario demonstrates that with continuous improvement, the goal of 40% carbon intensity reduction by 2020 announced in 2009 is possible, but will require strengthening or expansion of energy efficiency policies in industry, buildings, appliances, and motor vehicles, as well as further expansion of renewable and nuclear power capacity. These results emphasize the significant role that energy efficiency policies and subsequent improvements will continue to play in decreasing the growth of energy demand and leading China on a lower carbon development pathway. The crucial impact of energy efficiency improvements on carbon mitigation is most readily apparent in the power sector (vis-à-vis lowering electricity demand), as efficiency improvements and can actually outweigh CO_2 savings from decarbonized power supply through greater renewable and non-fossil fuel generation prior to 2030.

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